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RESEARCH ARTICLE

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Relationship between inferior vena cava diameter ratio and central venous pressure

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Abstract

Purpose: To explore the relationship between the shape of the inferior vena cava (IVC) lumen and central venous pressure (CVP).

Methods: In 60 patients undergoing mechanical ventilation and CVP monitoring in the Intensive Care Unit of Peking Union Medical College Hospital from July to October 2016, we measured with B-mode ultrasonography the transverse maximum (MXD) and minimum diameter (MID) of the IVC at end expiration, and calculated the diameter ratio (DR) as MXD/MID. Patients were divided into three groups according to CVP: low ($CVP < 8$ mm Hg), intermediate (8 mm $Hg \leq CVP \leq 10$ mm Hg), and high ($CVP > 10$ mm Hg).

Results: MXD was 2.32 ± 0.41 cm, MID was 1.41 ± 0.40 cm, and DR was 1.76 ± 0.49. CVP was 9.27 ± 2.99 mm Hg. DR correlated with CVP ($r = -0.527$, $P < .001$). The low-CVP group had greater dispersion of DR values, with a large variety in IVC shape (elliptical, irregular, teardrop-shaped, partially collapsed...). The area under the ROC curve for predicting CVP with DR, with a CVP threshold of 8 mm Hg was 0.835 (95% CI, 0.726–0.945; $P < .05$). With a DR cutoff value of 1.76, sensitivity was 0.765 and specificity was 0.781.

Conclusions: DR above 1.7 is predictive of $CVP < 8$ mm Hg.

KEYWORDS

central venous pressure, cross-section, diameter, inferior vena cava, ultrasonography

1 | INTRODUCTION

Central venous pressure (CVP), determined by the interaction of cardiac function, venous return, and blood volume, provides useful information about a patient's cardiovascular status.[1] Its meaning depends on the clinician's judgment. Many noninvasive methods for estimating CVP have been proposed in the clinical setting, among which ultrasonography is most commonly used. Ultrasonography can be used to measure diameter variations in the inferior vena cava (IVC), internal jugular vein, and peripheral veins, but also the inner diameter and flow velocity of the hepatic veins, the blood flow velocity in systemic veins or across the tricuspid valve (in Doppler mode), and the inner diameter of the right atrium.[2–5] Ultrasonography is a relatively simple and noninvasive technique for observing the IVC, and has become a preferred tool for CVP estimation. Measurements of IVC collapsibility index (IVC-CI) by Intensivist-performed bedside ultrasonography can provide a useful guide to noninvasive volume status assessment in intensive care unit (ICU) patients. Stawicki et al reported that IVC-CI correlated best with CVP in the setting of low (< 0.20) and high (> 0.60) collapsibility ranges.[4]

IVC measurement has become more common with advances in critical care ultrasonography. Observation of the IVC along its longitudinal axis in the subxiphoid area is the most common method, but it may be hindered by various factors (eg, drainage tubes, abdominal distension, wounds). A longitudinal view of the IVC can also be obtained via the right midaxillary line. In a previous study, we showed that the internal diameter of the IVC measured longitudinally with ultrasonography in the subxiphoid area differs from that obtained via the right

Qing Zhang and Xiaoting Wang contributed equally to this work.

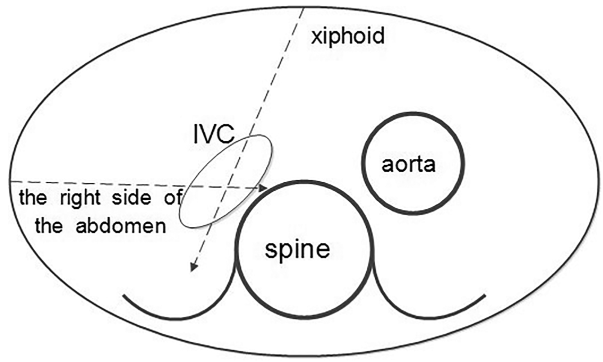

FIGURE 1 Schematic diagram of the inferior vena cava (IVC) on transverse section. Because the IVC can exhibit different shapes depending on blood volume and heart function, it can be approximated to an ellipse. Although the IVC diameters can be measured from either the subxiphoid area or the right midaxillary line, the resulting measurements may be notably different when performed on a longitudinal section. Especially at low CVP when the ICP shape is not circular

midaxillary line.[7] We found that this difference could be explained by the fact that the shape of the IVC in cross-section is highly variable (circular, elliptical, teardrop-shaped, irregularly shaped, or with partial collapse…). In addition, it changes (decrease or dilate) with breathing. In the supine position, the angle of collapse (ie, the minor axis relatively to vertical in the patient lying supine) assessed in the transverse plane averaged 115° (95%, confidence interval 112° to 118°)[8] (Figure 1). Measurements from the subxiphoid area and from the right midaxillary line would be similar, only if the IVC cross-section is circular and does not change with breathing, which is quite rare in clinical conditions.

To compare IVC measurements from the subxiphoid and from the right midaxillary approaches, we used ultrasonography to measure the transverse maximum (MXD) and minimum (MID) diameters. MID was the diameter measured perpendicularly at midpoint of MXD. We calculated the diameter ratio DR = MXD/MID. Prior study showed that DR of the IVC measured on computed tomography scans was related to the volume status,[9] but there have been fewer studies performed with ultrasonography. It has been shown that the DR measured from the two approaches is not significantly different.[10] Therefore, we hypothesized that the DR correlates with CVP.

2 | METHODS

2.1 | Patients

Patients admitted to the ICU of Peking Union Medical College Hospital from July to October 2016 were enrolled in this study. The research protocol was approved by the ethics committee of Peking Union Medical College Hospital (ethics code S-617). The inclusion criteria were: (1) patients under mechanical ventilation in whom the standard IVC measurements were feasible from the two approaches, yielding clear images; (2) patients needing CVP monitoring; and (3) patients whose CVP was not known by the examiner before the ultrasonographic examination.

2.2 | Techniques

Informed consent was signed by the guardian of the patients before measurements were made. Ultrasonography was completed within 48 hours after admission to the ICU.

2.2.1 | Assessment and measurements

Ultrasonography of the IVC was performed with a SonoSite M-Turbo or X-Porte ultrasonography apparatus (Fujifilm SonoSite, Bothell, WA) with a 1 to 5 MHz probe by examiners who were blinded to the patient's CVP.

The longitudinal plane of the IVC was first observed from the subxiphoid area. The standard measurement site was 0.5 to 1.0 cm distal to the IVC-hepatic vein junction or 2–3 cm distal to the IVC-right atrium junction. First, the site of the longitudinal measurement was moved to the center of the screen, followed by 90° clockwise probe rotation to obtain the transverse plane of the IVC. The probe was kept perpendicular to the sagittal plane so that the abdominal aorta, if visible, showed a circular section. After obtaining the transverse plane of the IVC, the image was frozen at end expiration and measurements were performed (Figure 2). Two measurements were performed for each variable, and their average value was calculated.

The CVP was measured and recorded using a standard method immediately after the IVC measurements were completed. Central venous catheters (Teleflex-Arrow International, Wayne, PA) were inserted in the subclavian or the internal jugular vein. A cardiovascular monitor (MP70 Intellivue, Amsterdam, the Netherlands) measured CVP with an effective range of 5.3–48.0 kPa and a precision of 3%. Mean values of three successive CVP measurements per investigation were calculated and averaged for analyze.[1]

Different CVPs can lead to different IVC shapes, contrary to an artery like the aorta, which, although pulsatile, keeps a circular cross-section. We divided the patients into three groups according to their CVP for further analysis: low (CVP < 8 mm Hg), intermediate (CVP ≥8 mm Hg but ≤ 10 mm Hg), and high CVP (CVP > 10 mm Hg).

All the echocardiographic measurements were performed by two experienced ICU physicians. All images were double-checked, then stored for analysis.

2.3 | Statistical analysis

Tests for normality and homogeneity of variances were performed. Comparisons of quantitative data among the groups were performed with analysis of variance. The chi-square test was applied for qualitative data. Pearson's correlation analyses were used to investigate the correlation between two indicators. Quantitative data are expressed as mean ± SD. All statistical analyses were performed with the IBM SPSS Statistics for Windows, Version 19.0 (IBM Corp., Armonk, NY). $P < .05$ was considered to indicate statistical significance.

3 | RESULTS

The study included 30 men and 30 women aged 56 ± 18 years. Patient heights were 167.2 ± 8.18 cm and weights were 66.45 ± 11.98 kg; the

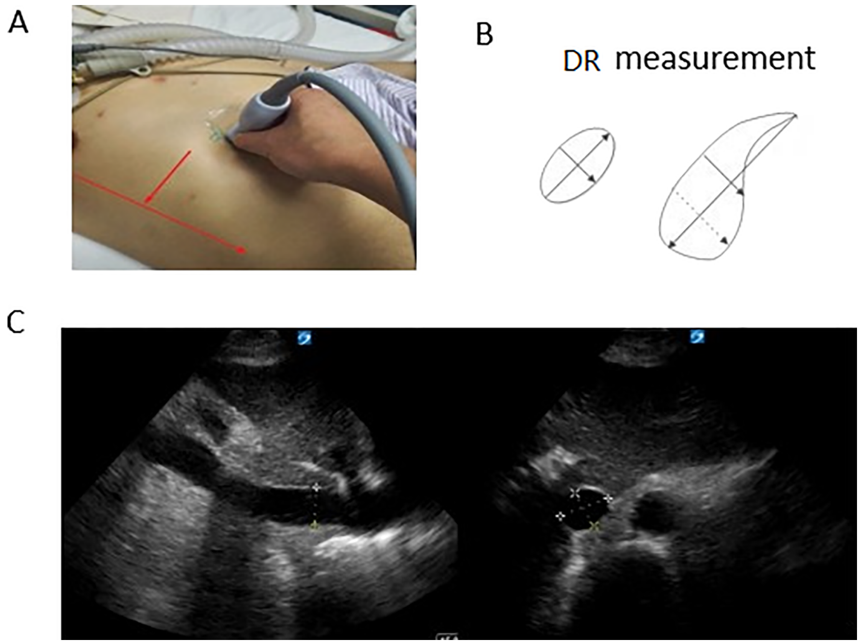

FIGURE 2 Measurement of the diameter ratio (DR) of the inferior vena cava (IVC). A, The IVC is visible on the longitudinal subxiphoid view. After the routine measurement site is moved to the center of the screen, the ultrasound probe is rotated 90° so that the probe is perpendicular to the sagittal plane of the body. B, After the major IVC diameter (MXD) is obtained, the minor diameter of the IVC is measured on a line perpendicular to the MXD at its midpoint. The solid line shows the correct measurement; the dotted line represents an erroneous measurement. C, Measurement of IVC diameter in longitudinal and transverse planes

body mass index was 23.8 ± 4.1 kg/m^2. Positive end-expiratory pressure (PEEP) was 6.05 ± 1.75 cm H_2O.

There were no differences in sex, age, body mass index, PEEP, or *Acute Physiology, Age, and Chronic Health Evaluation* (APACHE II) score among the three groups.

Pearson's analysis showed a negative correlation between DR and CVP ($r = -0.527$, $P < .001$).

The DR values in the high, intermediate, and low-CVP groups were 1.44 ± 0.22, 1.70 ± 0.40, and 2.15 ± 0.54, respectively ($P < .001$) (Figure 4). DR values were significantly greater in the low-CVP group than in the intermediate and high-CVP groups. The difference in DR between the intermediate and high-CVP groups was not significant. The dispersion of DR values was small in the intermediate and high-CVP groups but was relatively large in the low-CVP group (Figure 4).

The area under the receiver operating characteristics curve (ROC) for DR to identify high or low CVP was 0.835 (95% CI: 0.726–0.945; $P < .05$) (Figure 5). Based on the maximum Youden's index, a DR cutoff value of 1.76 was selected for discriminating high from low CVP (sensitivity 0.765, specificity 0.791).

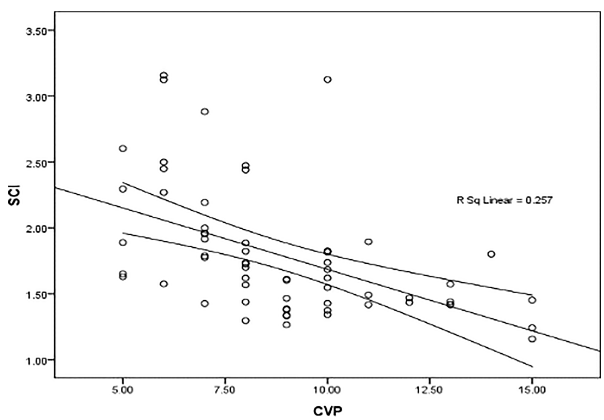

FIGURE 3 Correlation between central venous pressure (CVP) and the diameter ratio (DR) of the inferior vena cava. Pearson analysis showed a negative correlation between DR and CVP ($r = -0.527$, $P < .001$)

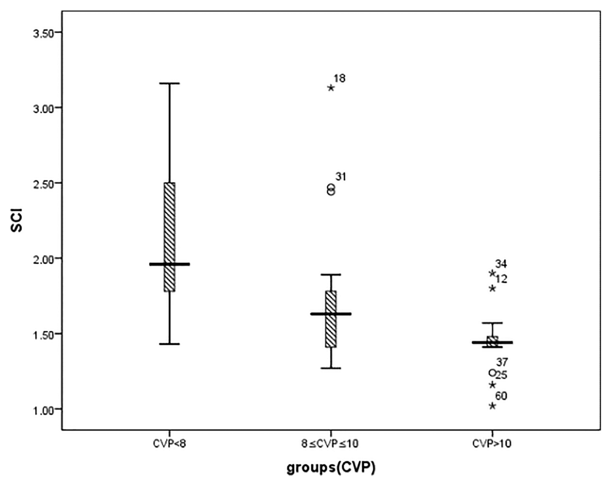

FIGURE 4 Comparison of and the diameter ratio (DR) values of the inferior vena cava among low, intermediate, and high central venous pressure (CVP) groups of patients. DR values were significantly greater in the low-CVP than in the intermediate and high-CVP groups ($P < .001$). The difference in DR between intermediate and high-CVP groups was not significant

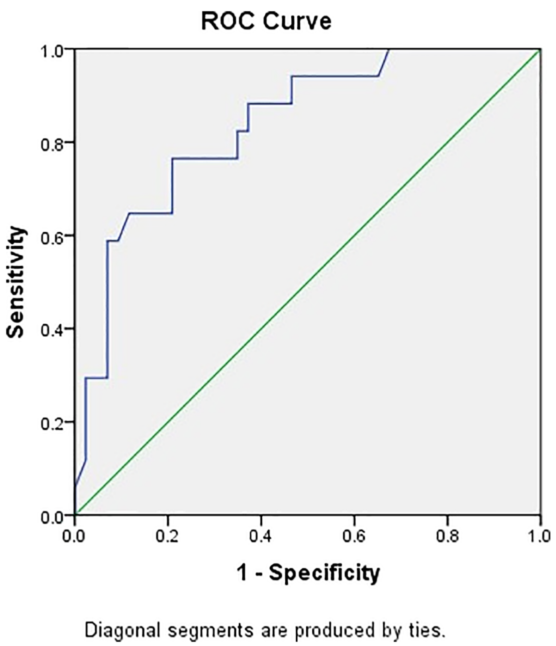

FIGURE 5 ROC curve for diameter ratio identifying high or low central venous pressure (CVP), with CVP = 8 mm Hg as the threshold. The area under the curve (AUC) for DR was 0.835 (95% CI: 0.726–0.945; $P < .05$). With 1.76l as the cutoff point, sensitivity was 0.765 and specificity was 0.791

4 | DISCUSSION

CVP is the blood pressure in the inferior and superior vena cava as they enter the right atrium. Clinically, when the IVC is observed via ultrasonography, its inner diameter, and its changes with respiration are often measured in the longitudinal plane. The degree of change is helpful for assessing volume status in critically ill patients, thereby informing their clinical management,[11–13] but differs between spontaneous breathing and mechanical ventilation. Accordingly, the concepts of IVC collapsibility and distensibility indices have been proposed.[14,15] In the current study, we investigated only the possible correlation between DR and CVP.

The assumption that DR correlates with CVP is based on the following considerations. The IVC is a capacitance vessel, whose shape changes with blood pressure. CVP depends on volemia and on the right heart function, which, in turn, depends on CVP (Frank-Starling law of the heart). For a given level of volemia, increased blood flow volume and/or velocity through the IVC, as resulting, for instance, from enhanced right ventricle function, is generally associated with lower blood pressure, and the IVC may collapse when transmural pressure becomes negative. In contrast, when flow volume and/or velocity decreases, for example, as a result of right heart failure, pressure within the IVC generally increases and the IVC becomes distended. Resulting changes in the shape of the IVC can be evaluated by DR. A smaller DR value means that the IVC is rounder in shape, whereas a larger SCI value often corresponds with an elliptical, teardrop-shaped, or irregularly shaped IVC. CVP measurement is typically performed at end expiration.[16] Similarly, DR is based on measurements obtained at end-expiration. Previous radiological studies that investigated morphological changes in the IVC[17,18] found a relationship between IVC morphology and IVC volume, but radiological studies are not easily performed in a clinical setting, especially in critically ill patients.

In the current study, DR negatively but moderately correlated with CVP ($r = -0.527$). We found greater dispersion of DR values in the low-CVP group. This may be explained by the fact that, in the low-CVP group, the IVC may exhibit very different shapes, being elliptical with various degree of eccentricity, teardrop-shaped, or even partially collapsed. Measuring the IVC cross-sectional area would be more suitable in these case, but also prone to artifacts (especially because of diffraction on the lateral walls, and if the ultrasound beam is not perfectly perpendicular to the ICV major axis). The degree of dispersion of DR values was least in the high-CVP group, although CVP was always ≤ 15 mm Hg, and DR values rarely approached 1. When DR approaches 1 (ie, when the IVC cross-section becomes circular), an additional increase in CVP would not change DR but only enlarge the cross-sectional area. As a lower CVP is associated with better clinical outcome[19] in this group, CVP is often lowered to a target level. There was no case with extremely high CVP in our series. As a result, there was no significant difference in DR values between the intermediate and high-CVP groups.

DR can be used to predict CVP to a certain degree. Using CVP > 8 mm Hg as a threshold, the DR cutoff value was 1.7. When the DR was less than 1.7 (predicting CVP above 8 mm Hg), the correlation between DR and CVP was good. Above 1.7 (predicting CVP below 8 mm Hg), the correlation between DR and CVP was poor. Thus, special attention is necessary when the IVC shape is elliptical, teardrop-shaped, or partially collapsed.

DR is a simple variable that can be easily obtained. MXD and MID are to be measured on a transverse cross-section, either from the

TABLE 1 General data in the three groups

Group	CVP < 8 mm Hg	8 mm Hg ≤ CVP ≤ 10 mm Hg	CVP > 10 mm Hg
Gender (Male/Female)	7/10	13/15	10/5
Age (years)	56 ± 14.6	56 ± 18.7	55 ± 21.7
Body mass Index	22.1 ± 3.54	23.8 ± 3.07	25.6 ± 5.47
APACHE II	17.11 ± 7.68	19.28 ± 7.12	20.86 ± 8.43
PEEP (cm H_20)	5.7 ± 1.68	5.8 ± 1.56	6.7 ± 2.08

Abbreviations: APACHE, acute physiology, age, and chronic health evaluation; CVP, central venous pressure; PEEP, positive end-expiratory pressure.

subxiphoid area or from the right midaxillary line, depending on availability. Our previous study demonstrated that measurements at these two sites are not significantly different.

Our study had some limitations. Ultrasonographic measurements can be altered if the beam is not perfectly perpendicular to the IVC. Therefore, the site for the longitudinal IVC measurement should first be moved to the center of the screen, followed by 90° clockwise rotation. A useful tip is to confirm that the aorta appears round at the time of measurement. We did not assess the patients' cardiac function and the volume responsiveness, which would have helped demonstrating the usefulness of DR more thoroughly.

5 | CONCLUSIONS

In mechanically ventilated patients, the diameter ratio of the IVC negatively correlates with CVP, with a value above 1.7 predicting CVP under 8 mm Hg. As the correlation between DR and CVP is moderate, especially in patients with low CVP, DR can be used only for identifying patients with low CVP, but not for accurate CVP evaluation.

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REFERENCES

[1] Magder S. How to use central venous pressure measurements. *Curr Opin Crit Care.* 2005;11(3):264–270.

[2] Beigel R, Cercek B, Luo H, Siegel RJ. Noninvasive evaluation of right atrial pressure. *J Am Soc Echocardiogr.* 2013;26(9):1033–1042.

[3] Pepi M, Tamborini G, Sganzerla P, et al. [The noninvasive estimation of right atrial pressure improves the Doppler evaluation of the pulmonary systolic pressure] (in Italian). *Cardiologia.* 1991;36:117–122.

[4] Stawicki SP, Braslow BM, Panebianco NL, et al. Intensivist use of hand-carried ultrasonography to measure IVC collapsibility in estimating intravascular volume status: correlations with CVP. *J Am Coll Surg.* 2009;209(1):55–61.

[5] Wiwatworapan W, Ratanajaratroj N, Sookananchai B. Correlation between inferior vena cava diameter and central venous pressure in critically ill patients. *J Med Assoc Thai.* 2012;95(3):320–324.

[6] Rudski LG, Lai WW, Afilalo J, et al. Guidelines for the echocardiographic assessment of the right heart in adults: a report from the American Society of Echocardiography endorsed by the European Association of Echocardiography, a registered branch of the European Society of Cardiology, and the Canadian Society of Echocardiography. *J Am Soc Echocardiogr.* 2010;23(7):685–713.

[7] Zhang Q, Liu D, Wang X, et al. [Inferior vena cava diameter and variability on longitudinal plane measured through ultrasonography from different sites: a comparison study] (in Chinese). *Zhonghua Nei Ke Za Zhi.* 2014;53:880–883.

[8] Blehar DJ, Resop D, Chin B, Dayno M, Gaspari R. Inferior vena cava displacement during respirophasic ultrasound imaging. *Crit Ultrasound J.* 2012;4(1):18.

[9] Li Y, Zhang LY, Wang Y, Zhang WG. The flatness index of inferior vena cava is useful in predicting hypovolemic shock in severe multiple-injury patients. *J Emerg Med.* 2013;45(6):872–878.

[10] Zhang Q, Liu D, Wang X, et al. [A pilot study of measuring inferior vena cava internal diameter on transverse section plane in different sites by ultrasonography] (in Chinese). *Zhonghua Nei Ke Za Zhi.* 2015;54:491–495.

[11] Vignon P, Repessé X, Bégot E, et al. Comparison of echocardiographic indices used to predict fluid responsiveness in ventilated patients. *Am J Respir Crit Care Med.* 2017;195(8):1022–1032.

[12] Bodson L, Vieillard-Baron A. Respiratory variation in inferior vena cava diameter: surrogate of central venous pressure or parameter of fluid responsiveness? let the physiology reply. *Crit Care.* 2012;16(6):181.

[13] Muller L, Bobbia X, Toumi M, et al. Respiratory variations of inferior vena cava diameter to predict fluid responsiveness in spontaneously breathing patients with acute circulatory failure: need for a cautious use. *Crit Care.* 2012;16(5):R188.

[14] Barbier C, Loubières Y, Schmit C, et al. Respiratory changes in inferior vena cava diameter are helpful in predicting fluid responsiveness in ventilated septic patients. *Intensive Care Med.* 2004;30(9):1740–1746.

[15] Moretti R, Pizzi B. Inferior vena cava distensibility as a predictor of fluid responsiveness in patients with subarachnoid hemorrhage. *Neurocrit Care.* 2010;13(1):3–9.

[16] Gill W, Champion HR, Angus P, McCloskey S, Cowley RA. Central venous pressure monitoring with positive end expiratory pressure. *J R Coll Surg Edinb.* 1975;20(3):163–165.

[17] Milia DJ, Dua A, Paul JS, Tolat P, Brasel KJ. Clinical utility of flat inferior vena cava by axial tomography in severely injured elderly patients. *J Trauma Acute Care Surg.* 2013;75(6):1002–1005.

[18] Nguyen A, Plurad DS, Bricker S, et al. Flat or fat? inferior vena cava ratio is a marker for occult shock in trauma patients. *J Surg Res.* 2014;192(2):263–267.

[19] Wang XT, Yao B, Liu DW, Zhang HM. Central venous pressure dropped early is associated with organ function and prognosis in septic shock patients: a retrospective observational study. *Shock.* 2015;44(5):426–430.

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